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(54) **MAGNETIC SENSOR SHIELD PINNED BY A HIGH-COERCIVITY FERROMAGNET**

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USPC 360/319, 324-324.2
See application file for complete search history.

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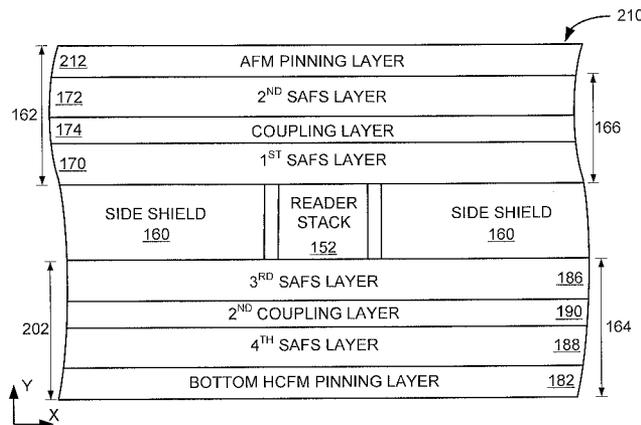
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(57) **ABSTRACT**

A magnetic sensor may generally be configured as a data reader capable of sensing data bits from an adjacent data storage medium. Various embodiments of a magnetic element may have at least a magnetic stack that contacts at least a first shield. The first shield can have at least one synthetic antiferromagnetic structure (SAFS) that is pinned by a high-coercivity ferromagnetic (HCFM) layer.

20 Claims, 5 Drawing Sheets



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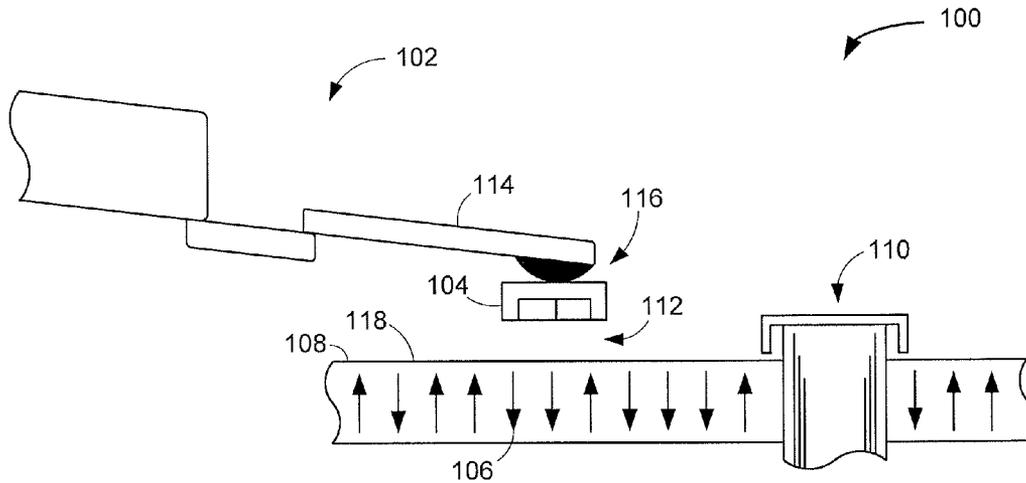


FIG. 1

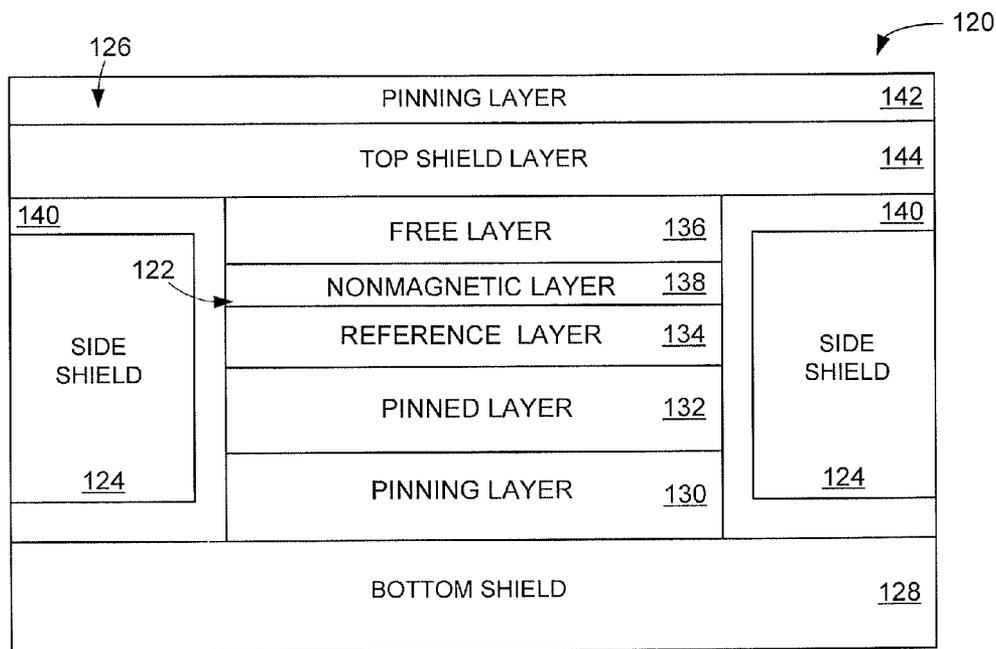
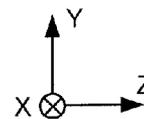


FIG. 2



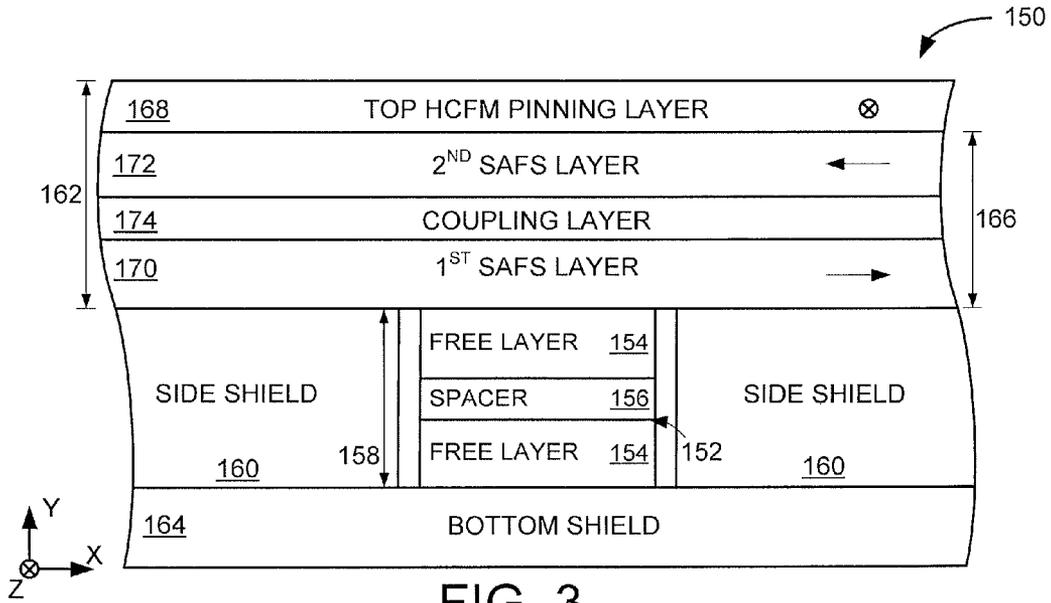


FIG. 3

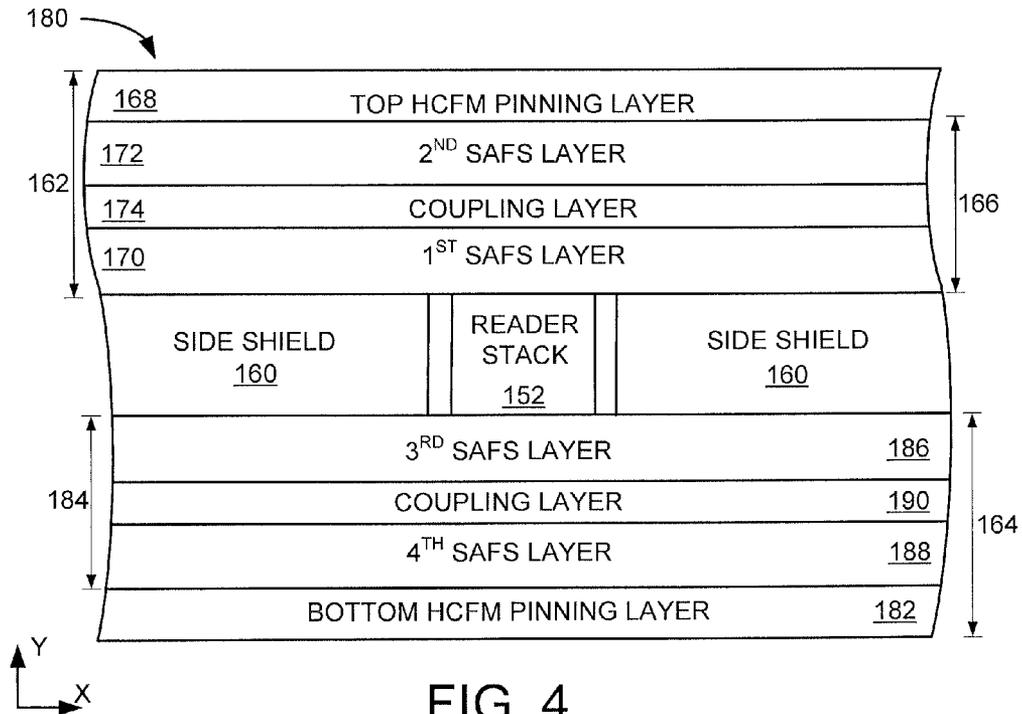


FIG. 4

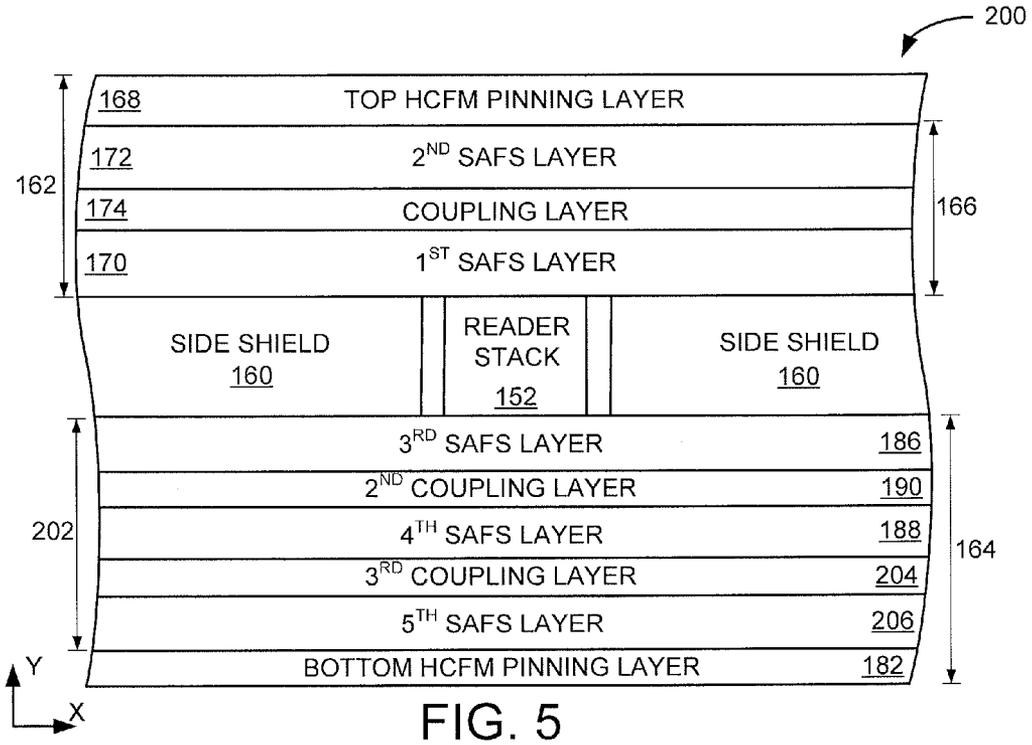


FIG. 5

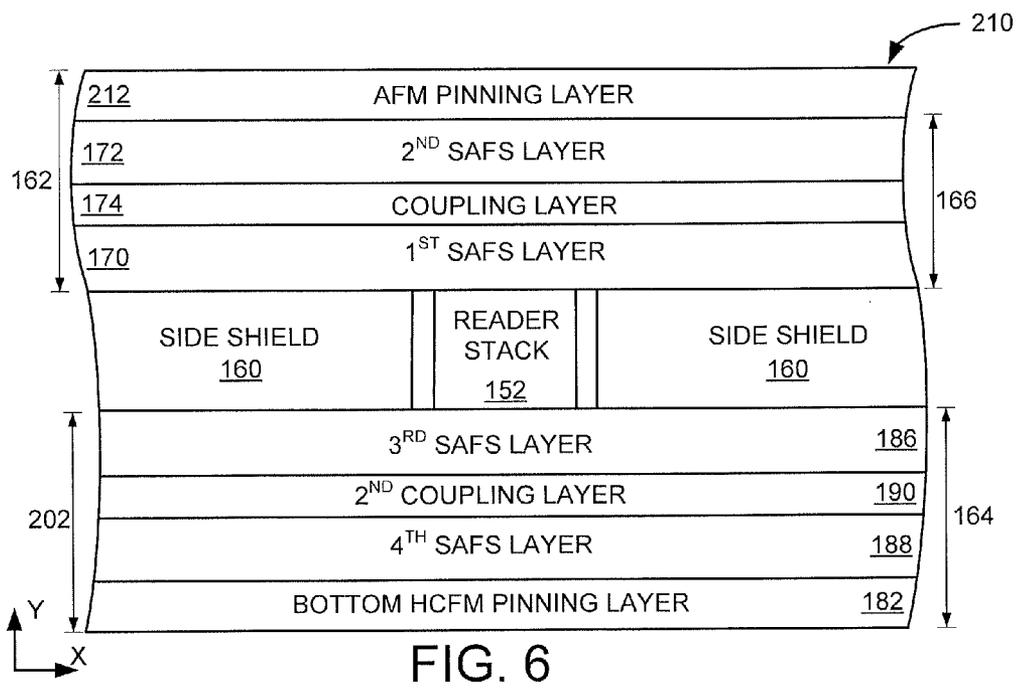


FIG. 6

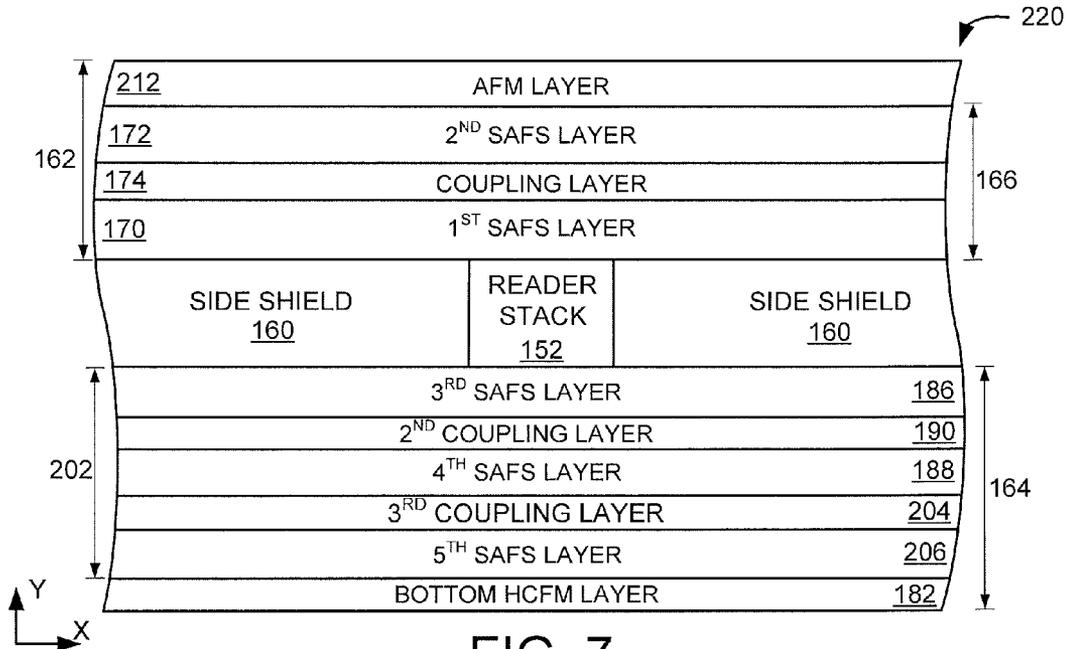


FIG. 7

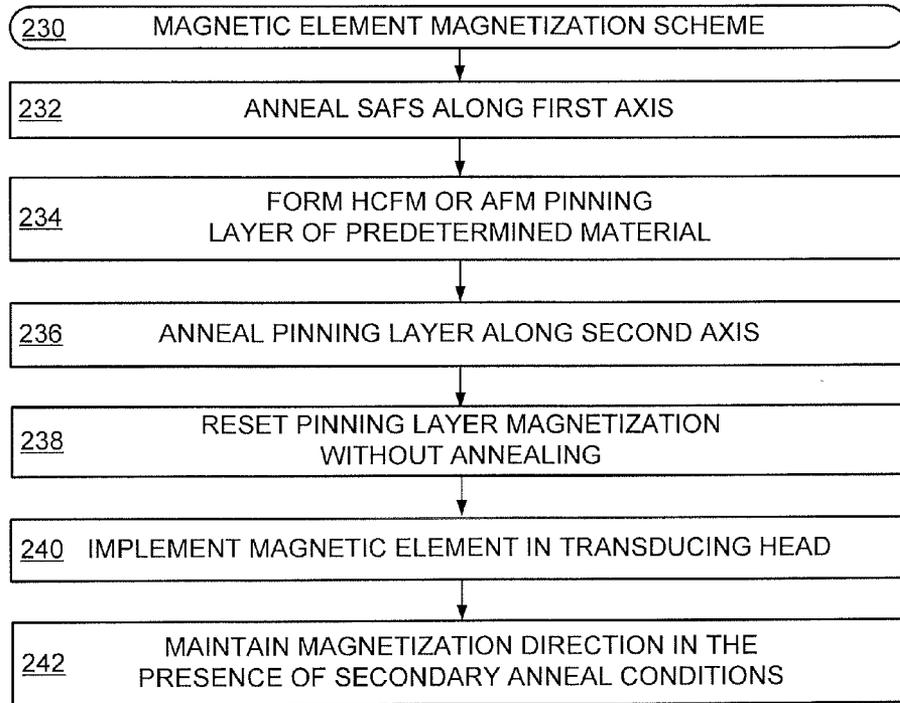


FIG. 8

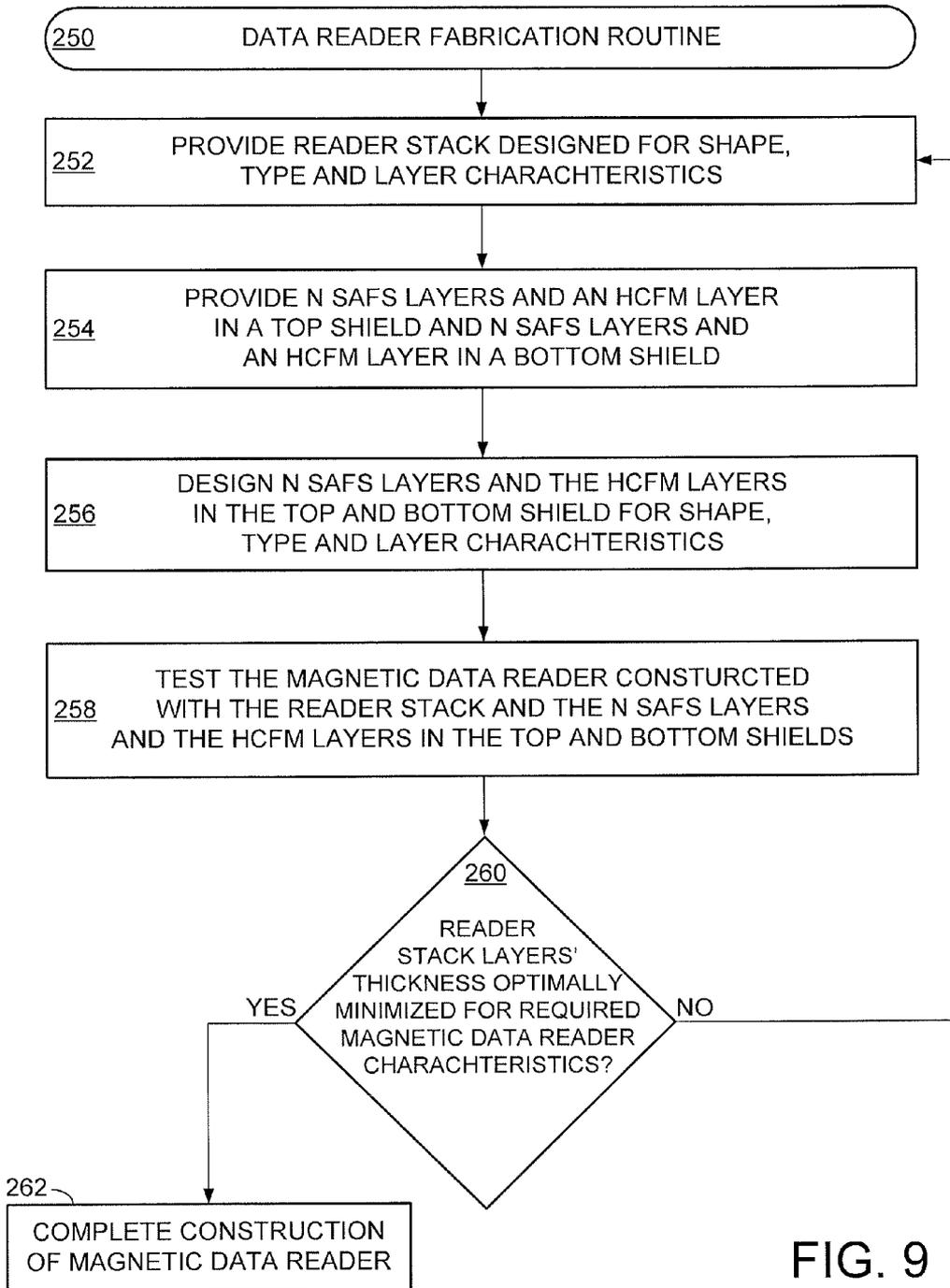


FIG. 9

MAGNETIC SENSOR SHIELD PINNED BY A HIGH-COERCIVITY FERROMAGNET

SUMMARY

Various embodiments are generally directed to a magnetic sensor capable of reading data bits.

Assorted embodiments configure a magnetic element with at least a magnetic stack that contacts at least a first shield. The first shield can have at least one synthetic antiferromagnetic structure (SAFS) that is pinned by a high-coercivity ferromagnetic (HCFM) layer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 provides a block representation of a portion of an example data storage device configured in accordance with various embodiments.

FIG. 2 shows an ABS view block representation of an example magnetic element capable of being used in the data storage device of FIG. 1.

FIG. 3 illustrates an ABS view block representation of a portion of an example magnetic element constructed and operated in accordance with some embodiments.

FIG. 4 is an ABS view block representation of an example magnetic element configured in accordance with assorted embodiments.

FIG. 5 displays an ABS view block representation of another example magnetic element constructed and operated in accordance with various embodiments.

FIG. 6 is an ABS view block representation of a portion of an example magnetic element configured in accordance with some embodiments.

FIG. 7 illustrates an ABS view block representation of another example magnetic element constructed and operated in accordance with assorted embodiments.

FIG. 8 maps an example magnetic element magnetization scheme carried out in accordance with various embodiments.

FIG. 9 is a flowchart illustrating steps of an exemplary magnetic element fabrication routine conducted in accordance with some embodiments.

DETAILED DESCRIPTION

Heightened industry demand for data storage devices with increased data storage capacity and reduced form factors has minimized the physical dimensions of data storage components. The reduction in physical dimensions has stressed the magnetic operation of some constituent materials, which may consequently jeopardize the magnetic stability, accuracy, and performance of a data storage component. For example, reduced physical dimensions can correspond with increased volatility to heat and external magnetic forces in magnetic shields that define the magnetic extent of a data bit reading sensor. Hence, increasing the magnetic stability of magnetic materials in reduced form factor, high data bit areal density data storage devices is a continued industry emphasis.

Accordingly, a magnetic sensor can be configured as a data bit reader with at least a magnetic stack contacting a first shield and the first shield having at least one synthetic antiferromagnet structure (SAFS) that is pinned to a predetermined magnetic orientation by a high-coercivity ferromagnetic layer (HCFM). The ability to pin the SAFS with a high-coercivity magnetic material provides optimized chemical stability, especially in reduced form factors, that produces a more robust bias magnetization to the shield as well as increased resistance to challenges of device integration, such

as varying magnetic fields, temperature, and oxidizing chemicals. That is, by using a HCFM layer in the top and/or bottom shield, the data reader may experience more precise bias magnetizations while having reduced stray magnetic field sensitivity.

While a magnetic element having a HCFM pinned shield can be practiced in a variety of non-limiting environments, FIG. 1 generally displays a data transducing portion 100 of an example data storage device configured in accordance with various embodiments. The transducing portion 100 is configured with an actuating assembly 102 that positions a transducing head 104 over programmed data bits 106 present on a magnetic storage medium 108 that is attached to, and rotates about, a spindle motor 110 to produce an air bearing surface (ABS) 112. The speed in which the spindle motor 110 rotates allows a slider portion 114 of the actuating assembly 102 to fly on the ABS to position a head gimbal assembly (HGA) 116, which includes the transducing head 104, over a desired portion of the medium 108.

The transducing head 104 can include one or more transducing elements, such as a magnetic writer and magnetically responsive reader, which operate to program data to and read data from the storage media 108, respectively. In this way, controlled motion of the actuating assembly 102 and spindle motor 110 can modulate the position of the transducing head both laterally along predetermined data tracks (not shown) defined on a storage media surface 118 and vertically as measured perpendicularly to the media surface 118 to selectively write, read, and rewrite data. With the data bits 106 being more closely packed onto the data storage medium 108 to produce a greater data bit areal density, the physical dimensions of the transducing head 104 and constituent transducing means reduce to accommodate a more precise magnetic extent of individual data bits 106.

FIG. 2 shows an ABS view block representation of an example magnetic data reader 120 capable of being used in the transducing portion 100 of the data storage device shown in FIG. 1. While not required or limited to the configuration shown in FIG. 2, the magnetic reader 120 has a magnetic stack 122 disposed laterally between magnetic side shields 124 and vertically between top 126 and bottom 128 shields on an air bearing surface (ABS). The magnetic stack 122 can be configured as a variety of different data bit sensing laminations, such as a magnetoresistive, tunnel magnetoresistive, spin valve, and a "trilayer" sensor with dual ferromagnetic free layers and without a fixed magnetization reference structure, but in the embodiment shown in FIG. 2, an abutted junction (HMRB) stack has a fixed reference structure containing pinning 130 and pinned 132 layers that sets a predetermined magnetization in a reference layer 134 while a magnetically free layer 136 is sensitive to external magnetic fields and contacts a non-magnetic spacer layer 138 opposite the reference layer 134.

While not required, various embodiments isolate the side shields 124 from the magnetic stack 122 and shields 126 and 128 with a non-magnetic insulating material 140 to balance magnetic shielding with reduced risk of magnetic shunting. However, other embodiments can couple one, or both, side shields 124 to another shield 126 and 128 to tune the magnetic shielding characteristics surrounding the magnetic stack 122. In the embodiment shown in FIG. 2, the top shield 126 is not coupled to or biased by a side shield 124, but instead by a pinning layer 142 that contacts and biases a shield layer 144 to a predetermined magnetization strength and direction that optimizes shield 126 stability and magnetic reader 120 performance.

When an antiferromagnetic (AFM) material, such as an IrMn alloy or ternary alloy where IrMn is supplemented by an additional element, is used for the pinning layer **142**, the intrinsic association of the exchange bias direction with the magneto-crystalline anisotropy of the AFM material is defined by the direction of a magnetic field used during elevated temperature annealing. The use of an AFM material allows moderate magnetic field and annealing temperature values to set the magnetization strength and direction in the pinning layer **142**. However, secondary conditions where magnetic fields and elevated temperatures are present, such as during implementation of the magnetic reader **120** into a data storage device, can inadvertently modify the magnetization of the pinning layer **142** and degrade magnetic reader **120** performance.

Additionally, some AFM materials can be susceptible to chemical volatility. For instance, corrosive oxidation can occur in the AFM material, particularly at the ABS where exposure to moving air is more prevalent. Such corrosive oxidation can degrade the magnetic characteristics and performance of the pinning layer **142**, which can consequently decrease the magnetic biasing performance and increase magnetic volatility of the top shield **126**. Accordingly, FIGS. **3-7** display ABS view block representations of portions of various example magnetic data readers constructed and operated in accordance with assorted embodiments.

In FIG. **3**, the example magnetic data reader **150** is displayed. The magnetic data reader **150** may be constructed with an unlimited variety of shield configurations, but in some embodiments the magnetic stack **152** is a trilayer lamination comprising multiple magnetically free layers **154** separated by a non-magnetic spacer layer **156**. The trilayer configuration of the magnetic stack **152** allows fixed magnetization means, such as the pinned **132** and pinning **130** layers of FIG. **2**, to be removed and shield-to-shield spacing **158** to be decreased as stack biasing means are positioned distal to the ABS, such as in the form of a rear biasing magnet.

The magnetic stack **152** is disposed laterally between side shields **160** and vertically between top **162** and bottom **164** shields. The magnetic reader stack **152** can be configured in any variety of trapezoidal, square, curvilinear, and shaped structures, but is shown in FIGS. **3-7** substantially as a rectangular shape. The side shields **160** positioned on opposite sides of the magnetic reader stack **152** can be tuned to individually unique or common materials, number of layers, and shape to decrease magnetic asymmetry in the reader stack **152** and reduce sensitivity to stray magnetic fields.

In the non-limiting embodiment of FIG. **3**, the top shield **162** is configured as a lamination of a SAFS **166** and a top HCFM pinning layer **168** that sets the first SAFS layer **170** and second SAFS layer **172** to a predetermined magnetization strength and direction relative to the ABS. Direct contact between the top HCFM pinning layer **168** and second SAFS layer **172** allows exchange coupling to bias the second SAFS layer **172** and antiferromagnetic coupling to bias the first SAFS layer **170** via the non-magnetic coupling layer **174**. Configuring the top HCFM pinning layer **168** of a ferromagnetic alloy of Pt or Pd can further allow the magnetization of the pinning layer **168** and the top shield **162** to be reset in any direction without annealing, which provides tuning options that can accommodate a variety of different data storage environments.

Construction of the top HCFM pinning layer **168** of a high-coercivity, permanent magnet, material with a coercivity of at least 2000 Oe can allow for precise magnetization tuning in the top shield **162** to optimize magnetic stability while providing increased resistance to corrosive oxidation.

As a non-limiting example, the top HCFM pinning layer **168** can be set to a predetermined first magnetization direction, such as orthogonal to the easy anisotropy axis of the SAFS **166** along the Z axis, while the SAFS layers **170** and **172** exhibit a predetermined second magnetization direction, such as along the easy anisotropy axis, parallel to the ABS, and along the X axis. Such orthogonal magnetization directions in the top shield **162** enhances magnetic stability and performance of the top shield **162**, which allows the magnetic stack **152** layers to have a reduced thickness and the magnetic reader **120** to have a reduced shield-to-shield spacing **158**.

While the tuned magnetization directions and increased resistance to corrosive oxidation can be exclusively utilized in the top shield **162**, as displayed in FIG. **3**, assorted embodiments configure the top **162** and bottom **162** shields as laminations with tuned magnetizations, as illustrated in FIG. **4**. In the example magnetic element **180** embodiment of FIG. **4**, the bottom shield **164** has a bottom HCFM pinning layer **182** that biases a bottom SAFS **184** disposed between the magnetic stack **152** and the pinning layer **182**.

It is contemplated that the bottom HCFM pinning layer **182** can be configured in any manner known by one of ordinary skill in art to have a similar or dissimilar structure and magnetic configuration compared to the top HCFM pinning layer **168**. Regardless of the material and magnetic construction of the bottom HCFM pinning layer **182**, a predetermined bias magnetization can be imparted on the third **186** and fourth **188** ferromagnetic SAFS layers through direct contact exchange coupling and antiferromagnetic coupling via the non-magnetic coupling layer **190**. The ability to tune the top **162** and bottom **164** shields to similar or dissimilar structural and magnetically operational characteristics allows the magnetic element **180** to have symmetrical or asymmetrical shielding for the reader stack **152** about the Y axis, which can correspond to the downtrack and uptrack directions with respect to a data track of a corresponding data storage medium.

While the shielding characteristics of the top **164** and bottom **164** shields can be tuned by adjusting the material, thickness along the Y axis, and magnetization directions, the shields may further be tuned to optimize reader stack **152** performance. FIG. **5** illustrates an ABS view block representation of an example magnetic data reader element **200** that has a bottom shield **164** tuned to have a SAFS **202** comprising multiple non-magnetic coupling layers **190** and **204** that separate the ferromagnetic SAFS layers **186**, **188**, and **206**. By tuning the various constituent layers of the SAFS **202** to be similar or dissimilar materials and thicknesses in association with the material and thickness of the bottom HCFM pinning layer **182**, magnetic shielding can be controlled to correspond to optimized data reader stack **152** performance, such as pulse width (PW50) at 50% of the peak amplitude.

The addition of the third coupling layer **204** and fifth SAFS layer **206** to the magnetic data reader element **200** can separate the permanent magnetization of the bottom HCFM pinning layer **182** from the reader stack **152** while providing multiple antiferromagnetic coupling means in the SAFS **202**. Through the tuned material and thickness selection of the constituent layers of the SAFS **202**, the high magnetic coercivity of the bottom HCFM pinning layer **182** can be translated into shielding means for the reader element **200** and biasing means for the reader stack **152** in the event the bottom shield **164** is magnetically coupled to the reader stack **152**.

Even though the use of HCFM in the top **162** and bottom **164** shields can provide more robust resistance to magnetic fields, temperature, and oxidizing chemicals compared to AFM pinning materials, reduction in the physical dimensions

of the magnetic data reader element **200** can position the potentially strong magnetizations of the HCFM close to the reader stack **152** and jeopardize reader stack accuracy. Accordingly, FIG. **6** shows an example magnetic data reader element **210** configured with an AFM pinning layer **212** in the top shield **164**, opposite the HCFM pinning layer **182** of the bottom shield **164**. The ability to have both a HCFM **182** and AFM **212** pinning layers provides tuning flexibility that can allow predetermined magnetization directions and strengths in all constituent layers of the top **162** and bottom **164** shields.

FIG. **7** displays yet another embodiment of a magnetic data reader element **220** in which the bottom shield **164** comprises multiple non-magnetic coupling layers **190** and **204** and anti-ferromagnetic coupling means while the top shield **162** comprises an AFM pinning layer **212**. The combination of the additional SAFS layers **204** and **206** to the AFM pinning layer **212**, in comparison with element **210** of FIG. **6**, illustrates the diversity of tuning options available to provide optimized shielding and performance to the reader stack **152**. For example, the AFM pinning layer **212** can be configured with a magnetization direction that is parallel to the ABS, X axis, and magnetization direction of the top shield SAFS layers **170** and **172** while the bottom HCFM pinning layer **182** has an orthogonal magnetization direction compared to the constituent layers of the SAFS **202**. Such asymmetrical shielding along the Y axis can provide a balance of shield magnetization strengths that optimize shielding with respect to magnetic responsiveness of the reader stack **152**.

It should be noted that the SAFS layers **170**, **172**, **186**, **188** and **206** can be any type of SAFS layer known to one of ordinary skill in the art. The HCFM layers **168** and **182** can be constructed of any material with satisfactory chemical and physical stability to magnetically bias the SAFS layers **170**, **172**, **186**, **188**, and **206**. In another embodiment of the present disclosure, the constituent layers of the magnetic stack **152** are tuned to minimize the size and thickness. In another embodiment, capping layers (not shown) can be disposed outside of and adjacent to the top HCFM pinning layer **168**, the bottom HCFM layer **182**, and/or the AFM pinning layer **212**. The capping layers can be manipulated similarly to the top HCFM pinning layer **168**, the bottom HCFM pinning layer **182**, and the AFM pinning layer **212** to assist in the tuning of the magnetic stack **122**.

It is contemplated that the magnetizations of the top **162** and bottom **164** shields can be tuned in a diverse variety of manners. However, assorted embodiments tune the shield magnetizations by carrying out the example magnetic element magnetization scheme **230** of FIG. **8**. The scheme **230** begins by forming a SAFS of a predetermined number of magnetic and non-magnetic layers before annealing the layers individually or collectively along a first axis in step **232**. As a non-limiting example, a SAFS was annealed at 225° C. for 2 hours with a 2000 Oe magnetic saturation along the easy anisotropy axis of the respective layers, which coincides with the X axis and ABS.

Next, step **234** forms a pinning layer atop the constructed SAFS with a predetermined material, such as a HCFM material or an AFM material. The formation of the pinning layer proceeds to step **236** where the pinning layer is annealed along a second axis that is orthogonal to the first axis. For instance, the pinning layer can be subjected to a magnetic saturation of 2 T along the Y axis, perpendicular to the ABS. It is noted that the annealing of step **236** does not involve an elevated temperature, although it may in some embodiments, which may alter the magnetizations of the SAFS layers. In the event an AFM material is used for the pinning layer, the

annealing conditions of step **236** are adjusted to accommodate the increased sensitivity of the AFM material to magnetic saturation and heat.

Subsequently, step **238** resets the magnetization of the pinning layer without annealing. The ability to reset the pinning layer magnetization without annealing allows the magnetization of the underlying SAFS to remain along the first axis, as opposed to if the pinning layer was annealed and the SAFS' magnetization would be altered. Resetting the pinning layer magnetization in step **238** proceeds to step **240** where the magnetic element is implemented into a transducing head as part of a data storage device incorporation plan. That is, step **240** can integrate the magnetic element from step **236** into a data storage device, which may involve at least the implementation of the magnetic element into a transducing head, the head assembled into a suspension, the suspension assembled into an actuating system, and the actuating system incorporated with a one or more data storage media.

The implementation of step **240** can then be followed by step **242** where the magnetization direction of the SAFS and pinning layer are maintained despite the presence of secondary annealing conditions, such as elevated temperatures and field-assisted annealing. Through the various steps of scheme **230**, the magnetization direction of at least one shield of a magnetic element can be tuned. However, the scheme is not limited to the steps of FIG. **8** as the assorted aspects can be conducted individually and sequentially on multiple shields with similar and dissimilar magnetization directions and annealing conditions.

Furthermore, scheme **230** may be conducted in concert with other magnetic element fabrication steps, such as the example data reader fabrication routine **250** shown in FIG. **9**. In accordance with various embodiments, routine **250** can be carried out initially by providing a reader stack that has been designed for shape, type and layer characteristics responsive to top and bottom shield configurations in step **202**. Step **254** can then provide N SAFS layers and an HCFM layer in a top shield and N SAFS layers and an HCFM layer in a bottom shield. The N SAFS layers and the HCFM layer in the top shield and the N SAFS layers and the HCFM layer in the bottom shield can be designed for shape, type and layer characteristics in step **256**.

The reader stack is disposed between the N SAFS layers and the HCFM layer in the top shield and the N SAFS layers and the HCFM layer in the bottom shield is disposed about the reader stack in step **258**. The bottom shield and top shield may include additional SAFS layers, as shown in FIGS. **3-7**. Step **258** tests the magnetic data reader to determine whether desirable characteristics are possessed by the magnetic data reader. Next, decision **260** evaluates if the reader stack has been optimized at least for thickness and performance per predetermined design specifications.

If decision **260** renders a lack of reader stack optimization, step **252** is revisited with an emphasis on meeting the predetermined design specifications, such as minimized shield-to-shield spacing. When decision **260** determines the reader stack complies with the design specifications, step **262** completes construction of the magnetic data reader with one or more processing steps, which can be any number and type of processes like polishing, lapping, and assembly into a data storage component.

With the diverse tuning options available by configuring one or more magnetic shields of a magnetic data reading element with a HCFM layer that pins a SAFS, structural and operational performance of the data reading element can be optimized. The increased chemical stability of the HCFM compared to an AFM can translate into increased shield sta-

bility by allowing orthogonal magnetization directions to be present in the shield and less susceptible to secondary annealing conditions that may occur during data storage device construction and data storage operations. Moreover, the chemical stability of the HCFM can provide enhanced robustness to corrosive oxidation that can degrade shield stability and data reading performance over time.

It is to be understood that even though numerous characteristics and configurations of various embodiments of the present disclosure have been set forth in the foregoing description, together with details of the structure and function of various embodiments, this detailed description is illustrative only, and changes may be made in detail, especially in matters of structure and arrangements of parts within the principles of the present disclosure to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed. For example, the particular elements may vary depending on the particular application without departing from the spirit and scope of the present technology.

What is claimed is:

1. An apparatus comprising a magnetic stack disposed between and contacting first and second shields, the first shield having at least one synthetic antiferromagnetic structure (SAFS) pinned by a high-coercivity ferromagnetic (HCFM) layer having a coercivity of at least 2000 Oe, the SAFS having first and second ferromagnetic layers each set with a first magnetization direction parallel to an easy axis of anisotropy by an annealing operation involving an application of heat and magnetization, the HCFM layer having a second magnetization direction oriented perpendicular to the first magnetization by a resetting operation involving an application of magnetization without heat, the second shield configured to provide asymmetrical shielding for the magnetic stack along a downtrack direction.

2. The apparatus of claim 1, wherein the magnetic stack comprises fixed and free magnetizations that form an abutted junction.

3. The apparatus of claim 1, wherein the magnetic stack comprises multiple free magnetizations without a fixed magnetization that form a trilayer sensor.

4. The apparatus of claim 1, wherein the HCFM layer is separated from the magnetic stack by a shield layer.

5. The apparatus of claim 4, wherein the shield layer comprises NiFe.

6. The apparatus of claim 1, wherein the HCFM layer comprises a ferromagnetic alloy of Pt.

7. The apparatus of claim 1, wherein the HCFM layer comprises a ferromagnetic alloy of Pd.

8. The apparatus of claim 1, wherein the magnetic stack is disposed between first and second side shields, the side shields separated from the magnetic stack by a non-magnetic material.

9. The apparatus of claim 8, wherein each side shield is separated from the first shield by the non-magnetic material.

10. The apparatus of claim 8, wherein the HCFM layer is exchanged coupled to the at least one SAFS.

11. A magnetic element comprising a magnetic stack disposed between and contacting first and second shields, the first shield having at least one synthetic antiferromagnetic structure (SAFS) pinned by a first high-coercivity ferromagnetic (HCFM) layer having a coercivity of at least 2000 Oe and constructed of an alloy of Pd, the SAFS having first and second ferromagnetic layers each set with a first magnetization direction parallel to an easy axis of anisotropy by an annealing operation involving an application of heat and magnetization the HCFM layer having a second magnetization direction oriented perpendicular to the first magnetization by a resetting operation involving an application of magnetization without heat, the second shield configured to provide asymmetrical shielding for the magnetic stack along a downtrack direction.

12. The magnetic element of claim 11, wherein the first shield comprises the first HCFM layer and the second shield comprises a second HCFM layer.

13. The magnetic element of claim 12, wherein the first and second HCFM layers are different materials.

14. The magnetic element of claim 12, wherein the second shield comprises two SAFS each pinned by the second HCFM layer.

15. The magnetic element of claim 12, wherein the second shield comprises three SAFS each pinned by the second HCFM layer.

16. The magnetic element of claim 11, wherein the second shield comprises a SAFS pinned by an antiferromagnetic (AFM) layer.

17. The magnetic element of claim 11, wherein the second magnetization direction is orthogonal to an air bearing surface of the magnetic stack.

18. An apparatus comprising a magnetic stack disposed between and contacting first and second shields, the first shield having at least one synthetic antiferromagnetic structure (SAFS) pinned by a high-coercivity ferromagnetic (HCFM) layer having a coercivity of at least 2000 Oe, the SAFS having first and second ferromagnetic layers each set with a first magnetization direction parallel to an easy axis of anisotropy by an annealing operation involving an application of heat and magnetization, the HCFM layer having a second magnetization direction oriented perpendicular to the first magnetization by a resetting operation involving an application of magnetization without heat, the second shield having at least one SAFS pinned by an antiferromagnetic (AFM) layer to provide asymmetrical shielding for the magnetic stack along a downtrack direction.

19. The apparatus of claim 18, wherein the at least one SAFS of the second shield having the first magnetization direction parallel to the easy axis of anisotropy.

20. The apparatus of claim 18, wherein the HCFM and AFM layers each are positioned on an air bearing surface with the magnetic stack.

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